Kinetic and training comparisons between assisted, resisted, and free countermovement jumps

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ABSTRACT

Elastic band assisted and resisted jump training may be a novel way to develop lower body power. The purpose of this investigation was to 1), determine the kinetic differences between assisted, free, and resisted counter movement jumps; and 2), investigate the effects of contrast training utilizing either assisted, free, or resisted countermovement jump training on vertical jump performance in well trained athletes. Part one: Eight recreationally trained males were assessed for force output, relative peak power ($PP \cdot kg^{-1}$) and peak velocity during the three types of jump. The highest peak force was achieved in the resisted jump method, while $PP \cdot kg^{-1}$ and peak velocity were greatest in the assisted jump. Each type of jump produced a different pattern of maximal values of the variables measured, which may have implications for developing separate components of muscular power. Part two: 28 professional rugby players were assessed for vertical jump height prior to and following four weeks of either assisted (n=9), resisted (n=11), or free (n=8) counter movement jump training. Relative to changes in the control group (1.3 ± 9.2 %, mean ± SD); there were clear small improvements in jump height in the assisted (6.7 ± 9.6 %) and the resisted jump training group (4.0 ± 8.8 %). Elastic band assisted and resisted jump training are both effective methods for improving jump height and can be easily implemented into current training programs via contrast training methods or as a part of plyometric training sessions. Assisted and resisted jump training are recommended for athletes where jumping, sprinting or explosive lower-body movements are performed as part of competition. Key Words. Elite athletes, in-season, vertical jump, rugby union.

INTRODUCTION

The ability to develop high levels of muscular power is critical for successful performance in many sports (18). However, as the training age of an athlete increases, there is a tendency toward a diminishing rate of improvement in muscular power (5). Furthermore, Argus and colleagues (2) recently reported that reductions in power may occur over a competitive season of professional rugby union. These points highlight the need to develop training methods that promote positive adaptation in power output in well trained athletes, especially during the competitive phase of a season.

As power is the product of force and velocity, manipulation of these two variables in a periodized resistance training program via alterations of the training loads may be essential for positive power adaptation (30). The better developed a single component; the less potential there is for power adaptation to occur; therefore training schemes need to focus on the components of power which are less developed. For example, athletes who have already acquired high levels of strength (force), the use of traditional strength training methods may be insufficient for enhancing explosive power. For these athletes more specific training interventions focusing on the velocity of the movement may be required to improve power output (23, 30). The use of assisted and resisted counter movement jump training with the aid of elastic bands may be a useful approach to manipulate the force velocity relationship and develop lower body power. Cronin and colleagues (12) reported improvements in peak movement velocity (5.4%), peak power (14.3%) and single leg jump height (2.5%) following ten weeks of ballistic training when resistance was added to a countermovement jump exercise by elastic bands. Alternately, several authors have reported that greater power output and velocities can be produced during unloaded /

assisted counter movement jumping (10, 22, 28), commonly with the aid of elastic bands (22, 28). Using elastic bands to perform assisted jump training therefore appears somewhat similar to overspeed sprint training.

It is commonly accepted that overspeed or downhill running can improve sprint performance. Corn and Knudson (11) reported a 7.1% increase in velocity in the acceleration phase of a 20 meter sprint using elastic cord to provide horizontal assistance. Additionally, Majdell and Alexander (26) reported increases in 40 yard sprint time following six weeks of overspeed sprint training. Thus, the possibility exists that assisted jump training might provide similar adaptations to those observed with overspeed or downhill running.

To date, research examining the kinetic differences between assisted, free (i.e. bodyweight) and resisted counter movement jumps is scarce. Understanding the kinetic characteristics of these jumps may help us to more accurately predict potential changes in performance following long term use. In turn, this understanding may allow for enhanced individualized prescription of training through more specific programming of separate components of muscular power (30).

One way in which plyometric jumps are often incorporated into a resistance training program is with a contrast loading scheme. Contrast training is a method that combines low and high velocity resisted movements by alternating an exercise set of moderate to heavy load with a similar exercise performed with a lighter load (4, 16). The moderate to heavy load is generally a strength-orientated exercise, whereas the lighter load is a velocity-orientated exercise, where acceleration occurs over the full range of the movement (4). Contrast training methods have been shown to acutely enhance power output in both upper and lower extremities by approximately 5% (3, 4, 35), although it has been suggested that this method may be more advantageous in athletes with relatively high levels of strength (4, 16).

Therefore the purpose of this investigation was to 1), determine the kinetic differences between assisted, free, and resisted counter movement jumps; and 2), investigate the effects of contrast training utilizing either assisted, free, or resisted countermovement jump training on vertical jump performance in well trained athletes. We hypothesized that 1) jumping with assistance would result in the greatest maximal velocity; and 2) due to the lack of previous overspeed training assisted jump training would produce the greatest improvements in jump height.

METHODS

Part One

Experimental Approach to the Problem

To determine the kinetic differences between assisted, free, and resisted counter movement jumps subjects performed three trials of each jump on a Kistler force plate (Kistler Instruments Inc, Winterthur, Switzerland) in a randomized order within a single session. Peak power relative to the adjusted bodyweight once assistance or resistance had been provided (PP·kg^{-1}) and peak velocity were determined for all jumps using the vertical ground reaction force data (15). Power was calculated using methods described in Dugan and colleagues (15) where (i) = time point based on sampling frequency, F = force, t = 1/sampling frequency, m = total mass, v = velocity, P = power:

$$v_{(0)} = 0$$

$$F_{(i)}t = m(v_{(i+1)} - v_{(i)})$$

$$\Delta v = (F_{(i)}t) / m$$

$$P_{(i)} = F_{(i)} * v_{(i)}$$

The absolute force trace (which included the unloaded or increased bodyweight once assistance or resistance had been provided) for each jump was analyzed in four separate phases (Figure 2). For each phase the peak force and rate of force development or unloading was calculated as the slope of the force-time curve from minimum force to peak force, or peak force to minimum force, respectively (8). These dependent measures were selected as they are considered important factors that contribute to explosive muscular power (30). Each subject performed two familiarization trials within the ten days prior to, but not within 36 hours of the testing day. Each familiarization trial consisted of each subject performing three sets of five repetitions for each of the three jump conditions.

Subjects

Eight recreationally trained men volunteered to participate in this part of the investigation (mean ± SD; age, 27.5 ± 5.5 years; height, 179.9 ± 4.9 cm; mass, 84.2 ± 14.3 kg). All subjects had been performing resistance training which included plyometrics twice a week for at least six months prior to the beginning of the investigation. None of the subjects were competing in any competitive sport at the time of assessment. Subjects were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for the use of human subjects.

Procedures

Warm-up

Subjects performed a standardized warm-up of two sets of ten bodyweight squats at a self-selected velocity followed by two sets of five free counter movement jumps performed with maximal effort. Each warm-up set was separated by a one minute rest period. Subjects then performed each of the three jump conditions in a randomized order. There were six randomized sequences of treatment (A-B-C, A-C-B, B-C-A, B-A-C, C-A-B, and C-B-A), which meant two sequences were performed twice.

Assisted Jumps

Subjects performed assisted jumps inside a squat cage whilst wearing a climber's harness. An elastic band was attached to either side of the harness at the hip level, with the other end attached to the squat cage above the subject. The harness straps were adjusted (tightened/loosened) so the elastic bands provided upward vertical tension which reduced the bodyweight of each subject by 20% when in a standing position on the force platform with hip and knee fully extended. The jump execution consisted of subjects lowering themselves to a self-selected depth and then jumping for maximal height. The assistance provided by the bands decreased as the subject left the ground following the concentric phase of the movement and was greatest as subjects lowered themselves to a self-selected depth. An arm swing was permitted during each jump but was abbreviated due to the placement of the elastic bands.

Resisted Jumps

Subjects performed resisted jumps inside a squat cage whilst wearing a climber's harness with an elastic band attached; the bands were attached to the squat cage below the subject. The harness straps were adjusted (tightened/loosened) so the elastic bands provided downward vertical tension which increased the bodyweight of each subject by 20% when in a standing position on the force platform with hip and knees fully extended. The resistance provided by the bands increased as the subject left the ground following the concentric phase of the movement and was at its least as subjects lowered themselves to a self-selected depth. The jump execution was consistent with that described above for the assisted jumps.

Free Jumps

Subjects performed free counter movement jumps with no assistance or resistance (i.e. bodyweight only). The jump execution was consistent with that described above for the assisted and resisted jumps (17).

Statistical Analyses

The greatest peak force during the loading phase was used to determine the best trial for each condition and was subsequently used for the analysis. All kinetic data were log-transformed to reduce non-uniformity of error, and the effects were derived by back transformation as percent changes (21). Standardized changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-subject standard deviation. Standardized changes of <0.2, <0.6, <1.2, <2.0 and >2.0 were interpreted as trivial, small, moderate, large, and very large effects (20). An effect size of 0.2 was considered the smallest worthwhile positive effect. To make inferences about true (large-sample) value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. The intraclass correlations for the each jump condition are presented in Table 1.

Insert Table 1 about here

Part Two

Experimental Approach to the Problem

This part of the study sought to investigate the effect of contrast training utilizing assisted, free, or resisted countermovement jumping on the vertical jump performance of rugby players. Subjects were assessed for maximal jump height and performed four weeks of contrast training consisting of a power clean exercise alternated with an assisted, free or resisted jumping exercise twice a week (Tuesday and Thursday am; Figure 1). Subjects were then re-assessed for maximal jump height at the end of the four week training phase. All training was performed in conjunction with, and during, the subject's regular training program. Jump height was chosen as the primary outcome measure as it is a reliable and valid measure for the assessment of lower body power and has been shown to correlate with sprint performance (34). Fifteen subjects were assessed one week apart to assess reliability of the measure. All assessments for vertical jump height were performed in the morning between 8.30am – 9.45am. All subjects were also requested to utilize similar nutrition and hydration strategies in the 24 hours proceeding each testing session.

Insert Figure 1 about here

Subjects

Twenty-eight professional rugby union players from a New Zealand Super 14 rugby team volunteered to take part in this study during their competitive season (Table 2). Each subject had been performing intensive and regular resistance training for a minimum of two years. The subjects were matched for jump height and playing positions, and were placed into one of three separate training groups: assisted jumps (n=9), free jumps (n=8), or resisted jumps (n=11). Subjects were informed of the experimental risks and signed an informed consent document prior to the investigation. The investigation was approved by an Institutional Review Board for the use of human subjects.

Insert Table 2 about here

Procedures

Performance Assessment

Jump height was assessed using a counter movement jump. Subjects completed a standardized warm-up of two sets of ten bodyweight squats at a self selected velocity followed by two sets of five free counter movement jumps performed with maximal effort. Subjects then performed two sets of four maximal countermovement jumps with the highest jump used for analysis (31). Three minutes of rest was allowed between each set. Jump height was assessed and recorded using a Gymaware™ optical encoder (50 Hz sample frequency with no data smoothing or filtering; Kinetic Performance Technology, Canberra, Australia) using the methods described elsewhere (14). Briefly, Gymaware® consists of a spring-powered retractable cord that passes around a pulley mechanically coupled to an optical encoder. The retractable cord is then attached to the broomstick and displacement is calculated from the spinning movement of the pulley upon movement of the barbell. The encoder gave one pulse approximately every three millimeters of load displacement, with each displacement value time stamped with a one-millisecond resolution (14).

Training

All subjects performed four repetitions of a power clean exercise 60 seconds prior to six repetitions of assisted jumps, resisted jumps, or free jumps. Each subject performed this for three sets, with three minutes rest between each set. The load lifted for the power clean exercises was between 50% and 70% of one repetition maximum and was dependent on the training microcycle for each individual. Variation in the load lifted was due to a greater volume of rugby union game time completed by some subjects.

Assisted Jumps

Assisted jumps were performed in the same manner as described for part one, but without rest between each repetition. The elastic bands provided upward vertical tension which reduced the bodyweight of each subject by 28 ± 3 % when the subject was in a standing position with the hip and knee fully extended. Each participant was weighed on two separate occasions to assess the assistance provided. The assistance varied from part one as no adjustments (tightening or loosening) were made to the harness; time constraints of the training session made it impossible to weigh and adjust the weight of each athlete prior to each set of jumping.

Resisted Jumps

Resisted jumps were performed as described in part one, but without rest between each repetition. The elastic bands provided a downward vertical tension, which increased the load by 27 ± 5 % above bodyweight when subjects were in a standing position with their hips and knees fully extended.

Free Jumps

Free jumps were performed as described for part one.

Additional Training

All jump training was performed in conjunction with, and as part of, the subject's regular resistance training sessions. Each week the subjects typically performed two resistance training sessions (30-50 min, 4-6 exercises, 1-6 repetitions [strength/power], 2-3 min rest), one speed development session (20-30 min, including fast foot ladders, mini hurdles, weighted sled towing, maximal sprinting), four team training sessions (30-75 min, including specific rugby skill, tactical, tackling, etc), one competitive match, and one recovery session (20-40 min, including light exercise, stretching, hot and cold baths).

Statistical Analyses

All data were analyzed in the same manner as part one. Changes in jump height were presented as mean ± standard deviations, while comparisons between training conditions were presented as mean ± 90% confidence limits. An effect size of 0.2 was considered the smallest worthwhile positive effect. Validity of the Gymaware™ optical encoder has been previously reported elsewhere (14). The coefficient of variation (CV) and intraclass correlation (r) for the vertical jump height performance by the subjects was 4.3% and 0.83, respectively.

RESULTS

Part One

The peak vertical velocity attained in the loading phase (Phase B, Figure 2; Table 1) of the assisted jump was 37.4% (±5.3%; 90% confidence limits, CL) and 6.3% (±3.7%) greater than attained in the resisted and free jump (effect size [ES], very large and moderate, respectively). A very large difference (33.5 ±6.8 %) in velocity between the free and resisted jump was also observed (Table 3).

Insert Figure 2 about here

Insert Table 3 about here

Relative peak power was greatest in the assisted jump and was 35.0% (±22.7%) greater than the resisted jump (very large ES). Additionally peak power ($W \cdot kg^{-1}$) was 34.0% (±13.7%) greater in the free than the resisted jump (very large ES). There was no difference in relative peak power between the free and assisted jump conditions (Table 1). Figure 3 illustrates the variation in velocity, peak power, and peak force, in the separate countermovement jumps between subjects.

Insert Figure 3 about here

The amplitude of force unloading during the early unloading phase (Phase A) of the jump was 16.9% (±17.1%) greater in the resisted jump than the assisted jump (moderate ES). There was no difference in the rate of force unloading during the early unloading phase.

The peak force produced during the loading phase (Phase B) was 5.8% (±6.4%) and 17.2% (±5.8%) greater in the resisted jump than the free and assisted jumps (small and moderate ES, respectively). Additionally peak force was 10.7% (±4.0%) greater in the free jump compared to the assisted jump (small ES). A small difference was observed in the change in force during the loading phase and was 7.9% (±11.5%) greater in the resisted jump when compared to the assisted jump method.

The rate of force development, measured as the slope of the force-time curve in the loading phase (Phase B), was greatest in the resisted jump (4268 ± 2125 $N.ms^{-1}$). A moderate difference of 21.6% (±26.5%; 90% CL) was observed in the rate of force development during the loading phase between the resisted jump and free jump.

The rate of force decline, calculated as the (negative) slope of the force-time curve from peak force to zero force (Phase C) was greatest in the resisted jump when compared to free (19.5 ±22.5 %; 90% CL) and assisted jumps (78.2 ±75.7 %; 90% CL) and represented a small and moderate effect size, respectively.

The greatest impact force was generated in the resisted jump (Phase D) and was 66.5% (±41.3%; 90% CL) and 22.0% (±25.0%; 90% CL) greater than the assisted jump and resisted jump, respectively (ES, moderate). Additionally the free jump produced 36.4% (±35.3%; 90% CL) greater force on impact when compared to the assisted jump (ES, moderate). Similarly the greatest rate of force development on impact was generated in the resisted jump, being 98.7% (±45.8%; 90% CL) and 35.7% (±33.4%; 90% CL) greater than the assisted jump and free jump (ES, moderate and small, respectively). Additionally the rate of force development on impact was 46.4% (±39.8%; 90% CL) greater in the free jump when compared to the assisted jump (ES, moderate).

Insert Table 2 about here

Part Two

The analysis revealed that both assisted and resisted jump training groups had a small increase in jump height of 6.7% (± 9.6%) and 4.0% (± 8.8%), respectively, whilst the free jump group produced a trivial increase in jump height of 1.3% (± 9.2%). A small effect was observed for the between-group difference in the change in jump height between assisted and free jump training (5.6, 90% confidence limit ±6.8%), and resisted and free jump training (3.7 ±6.1 %). Trivial but unclear between-group differences were observed in the change in jump height between the assisted and resisted jump training protocols. Figure 4 illustrates the variation in vertical jump height change of each subject in the three separate conditions.

Insert Figure 4 about here

DISCUSSION

The purpose of part one was to examine the differences in the kinetics of assisted, resisted, and free counter movement jumps. The findings were then used to help plan and implement the training protocols in part two, which examined the difference in training effect of these training methods.

As expected from the concentric force-velocity relationship, the greatest peak velocity was achieved during the assisted jump as the vertical assistance provided by the elastic bands reduced the effective bodyweight of the subject by providing an upward propulsive force. The assisted jump therefore allowed subjects to jump more quickly than is possible without assistance. Previous literature has shown increased neural activation (via IEMG) when performing at supra-maximal velocities (29) that may have positive training implications. The greatest peak power relative to bodyweight was also achieved in the assisted jump condition, with this effect likely due to the increased velocity of the movement.

There was a reduced amplitude of force unloading in the early unloading phase of the assisted jump in comparison to resisted and free jumps, and may have reflected in some ways a decreased stretch-shortening cycle force contribution. Reductions in force unloading and rate of unloading may have resulted in less stretch on the muscle-tendon complex, and therefore the tendon would have recoiled with reduced force (24). As such the total force produced during the assisted jump would have had a greater reliance on concentric-only muscle force production which may help to explain the smaller change in force compared to the resisted jump during the loading phase (24).

The assisted jump was associated with substantially smaller impact forces than both resisted and free jumps. In a training environment, the reduced impact forces observed during assisted jumps may be a safer way to graduate the intensity of plyometric loading, especially following recovery from lower-body injury.

Maximum force, rate of force development and impact force were greatest in the resisted jump condition. The observation that the resisted jump condition allowed the greatest peak force is likely due to the increased resistance reducing movement velocity. Indeed, according to the force-velocity relationship, force is greater at slower concentric contraction speeds and reduces as the velocity of the concentric action increases (19). In contrast to assisted jumping, the greater force and rate of force development produced in the resisted jumps may have been due to the larger force unloading in the early unloading phase of the jump. Greater unloading forces and rate of force unloading during this phase may have increased tendon recoil thus enhancing stretch-shortening cycle function. Indeed Kubo and colleagues reported that a faster pre-stretch of human muscle led to greater muscle-tendon complex lengthening with 22.3% greater work completed in the following concentric action than at a slower pre-stretch rate (24).

It is well known that power production during complex movement is influenced by many different factors (e.g. force, velocity, rate of force development, stretch-shortening cycle efficiency) (30). Part one of this investigation determined that both assisted and resisted jump methods produced distinct maximal outputs, which may be expected to develop different components of muscular power (high speed / low force and low speed / high force, respectively).

The free jump did not result in a greater output than the assisted or resisted jumps in any of the measured variables.

There are some limitations which should be considered before attempting to interpret the results from part two of this investigation. Firstly, the assistance and resistance provided varied between participants and was not assessed on every set of every training session; and secondly, the competition game performed by the subjects could not be completely controlled in terms of specific role each athlete played within the match, tasks completed or time on the field.

Results of part two indicated that assisted and resisted jump training led to small improvements (4.0-6.7 %) in vertical jump height in well-trained rugby players during the competitive phase of their season. These findings are important considering prior research from this group indicating a 3.3% decrease in lower body power in similar well trained rugby players over a competitive season (2). Trivial improvements (1.3 ± 9.2 %) in jump height were observed following free counter movement jump training. It is important to note that in similar well-trained athletes Baker and Newton (5) reported 5% improvements in power over a four year training period, as such, trivial performance improvements may still be important. If 1-2% improvements can be achieved by athletes with minimal disturbance to training, without risk of injury and at minimal cost, then coaches might confidently employ such training methods.

Assisted jump training resulted in the greatest increase in vertical jump height and was associated with the greatest acute peak velocity and power outputs. Findings from part one revealed that performing assisted jump training allowed participants to jump with a movement velocity greater than in the free and resisted jump conditions. Training at a higher movement speed may have resulted in decreased antagonist co-activation or an increase in MHC-II fiber activation (1). Indeed, there is a close relationship between muscle shortening speeds and the expression of the different (MHC) isoforms (9, 25). Additionally, muscle fibers that contain MHC-I have slower maximal shortening velocities and lower power outputs than muscle fibers containing MHC-II isoforms (9, 25). Although it was not assessed in this investigation, our results may suggest that the higher velocity training resulted in very specific morphological adaptations. Neuromuscular adaptations should not be discounted as possible mechanisms for the improvements observed in jump height. Indeed, Newton and colleagues (32) reported that greater velocity and force production (as observed in assisted and resisted jumps, respectively) provides superior loading conditions for the neuromuscular system. As such, the greater stimulus may have promoted positive adaptation (6).

Resisted jump training improved vertical jump height by 4.0% and was associated with the greatest peak force and rate of force development. It is likely that the increased force requirements of resisted jumping led to positive adaptation. Attempting to move at high speeds against a larger external load may induce numerous adaptations including an increase in contractile force, perhaps through increased neural activation, reduced co-activation, and muscle architectural and fiber size adaptations, although the mechanisms are yet to be completely defined (7, 12, 27, 31).

In support of the current findings, Cronin, McNair and Marshall (12) reported that resisted bungy countermovement jump training (performed on a isoinertial supine squat machine) improved a variety of lower-body strength and power measures following a ten-week training phase. Cronin and colleagues (12) also reported that resisted bungy countermovement jump training produced greater EMG activity (70-100%) during the later stages of the eccentric phase of the jump, when compared to the free jump method. Accentuated eccentric loading increases the force that can be produced in the concentric phase of the movement, and may be due to increased elastic energy storage as a result of the greater eccentric load increasing tendon elongation (13). Sheppard and colleagues (33) reported that five weeks of accentuated eccentric loading countermovement jump training increased vertical jump height by 11% in high performance volleyball players. The increase was significantly larger than the control group who performed regular counter movement jumps. Therefore improvements in vertical jump following resisted jump training might also be related to an increased eccentric loading following the flight phase of the jump, and similar to those observed following drop jump training.

The free jump group produced a trivial increase in vertical jump. The lack of improvement may be due to the subject's regular use of the free jumps as part of their training program prior to the beginning of the study. As such the kinetic components of power that are optimized by free jump training may have been previously developed, thus, there was less potential for adaptation to occur (33).

PRACTICAL APPLICACTIONS

Inclusion of both assisted and resisted jumps in a conditioning program The addition of assisted or resisted jumping (three sets of six) twice a week to a training program can improve vertical jump height over a four week training phase. Conditioning coaches and athletes can simply integrate these methods of jump training into their current resistance training via contrast training methods or as a part of their plyometric training sessions. The improvements in jump height in the current investigation were made in well trained rugby athletes; however, we believe that the improvements are not limited to this form of athlete and should be performed by any athlete where jumping, sprinting, or any explosive lower-body movements are performed in competition. Finally, assisted jumping may also provide a lower impact method of plyometrics which may be useful for progressing the intensity of plyometric loading following lower-body injury or for heavy athletes who do not tolerate the high impact ground reaction forces on landing. Future research in this area should look at investigating the effects of individualized prescription of assisted compared to resisted jump methods for athletes with limitations in their velocity and force components of power, respectively. When combined with appropriate testing methodologies, such an approach may maximize the potential for power gain in these athletes.

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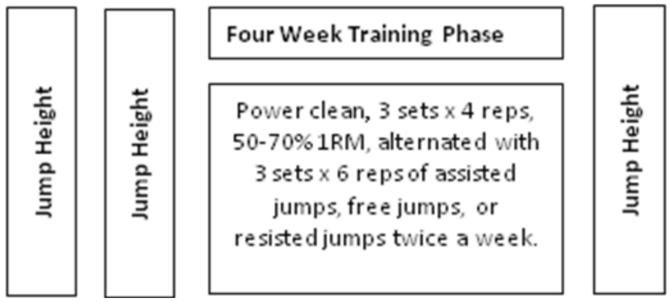
Figure Legends

Figure 1. Outline of assessment and training in elite rugby union athletes. Seven days separated jump height assessments and training phases. Reps, repetitions; RM, repetition maximum. Assisted jumps, n=9; free, n=8; resisted jumps, n=11.

Figure 2. Example from one participant of forces produced in the three different jump conditions. The different phases of the movement have also been labeled (resisted jump only). A, early unloading phase; B, loading phase; C, unloading phase prior to flight; D, impact.

Figure 3. Subject variation (n=8) in peak velocity, peak power, and peak force, in three separate countermovement jumps, assisted, free, resisted. * peak ground reaction force during the concentric phase of the jump prior to flight. W, watts.

Figure 4. Subject variation in vertical jump height change following a four week training phase of assisted (A, n=9), free (B, n=8), or resisted (C, n=11) countermovement jumps.



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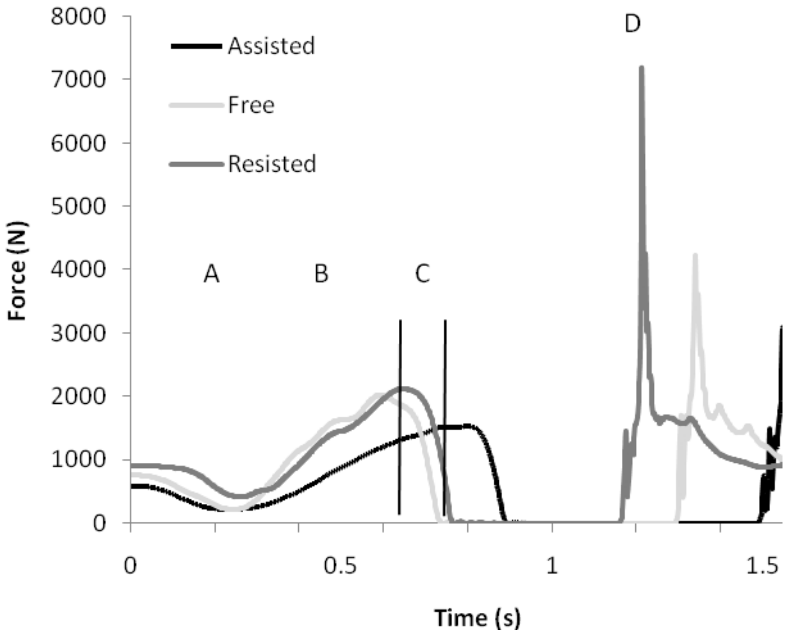

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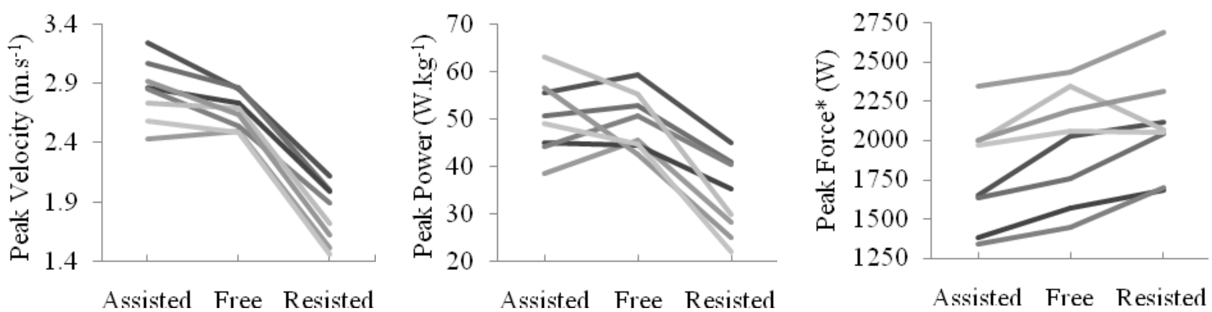

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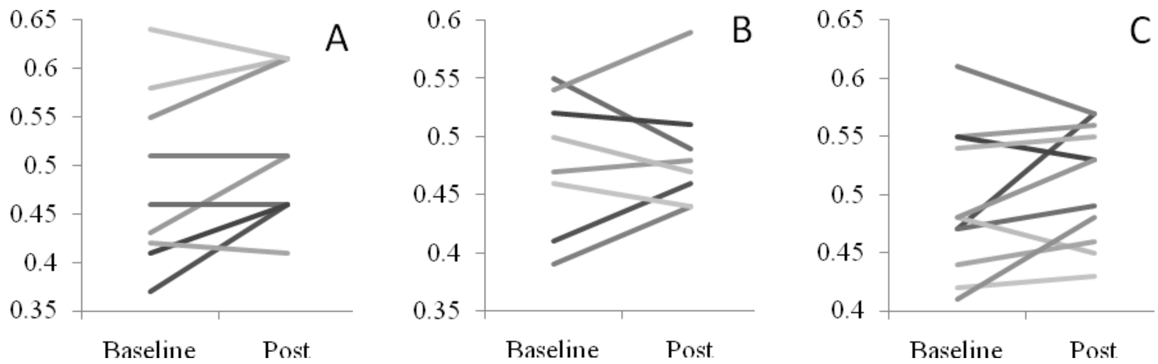

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Table 1. Intraclass correlations (r) of peak force, peak velocity and peak power in three different countermovement jumps (assisted, free, resisted) performed by eight recreationally trained men.

	Assisted	Free	Resisted
Force	0.964	0.987	0.996
Velocity	0.860	0.985	0.849
Power	0.908	0.990	0.989

Table 2. Subject characteristics of three separate countermovement jump training groups.

	Assisted (n=9)	Free (n=8)	Resisted (n=11)
Age (y)	25 ± 2	24 ± 2	23 ± 2
Height (cm)	184 ± 8	186 ± 6	183 ± 4
Mass (kg)	101 ± 10	101 ± 10	100 ± 4

All data is mean ± standard deviation.

Table 1. Relative peak power and peak velocity produced in three different counter movement jump conditions (assisted, free, and resisted).

	Assisted (mean ± SD)	Free (mean ± SD)	Resisted (mean ± SD)
Peak Power ($W.kg^{-1}$)	50.4 ± 8.0$^{\#}$	49.4 ± 6.0$^{\#}$	33.3 ± 8.3
Peak Velocity ($m.s^{-1}$)	2.8 ± 0.3$^{\#*}$	2.7 ± 0.2$^{\#}$	1.8 ± 0.3

SD, standard deviation. n = 8. #, very large effect size vs. resisted jumps; *, moderate effect size vs. free jumps.

Table 2. Comparison of jump force data between assisted, free and resisted countermovement jumps in eight recreational level subjects.

	Assisted (mean ± SD)	Free (mean ± SD)	Resisted (mean ± SD)
Phase A: Early Unloading Phase			
Max (N)	680 ± 110	840 ± 140	1030 ± 180
Min (N)	230 ± 130	360 ± 150	500 ± 240
Amplitude (N)	440 ± 100	490 ± 220	540 ± 230
Rate (N.ms^{-1})	-2.1 ± 1.2	-2.1 ± 1.1	-2.6 ± 1.7
Phase B: Loading Phase			
Max (N)	1790 ± 350	1980 ± 360	2080 ± 320
Min (N)	230 ± 130	360 ± 150	500 ± 240
Amplitude (N)	1550 ± 270	1620 ± 430	1580 ± 240
Rate (N.ms^{-1})	3.4 ± 1.3	3.5 ± 1.7	4.3 ± 2.1
Phase C: Unloading Phase Prior to Flight			
Max (N)	1790 ± 350	1980 ± 360	2080 ± 320
Rate (N.ms^{-1})	-11.3 ± 6.5	-15.1 ± 6.5	-17.3 ± 5.5
Phase D: Impact			
Max (N)	3180 ± 1260	4130 ± 840	5330 ± 1970
Rate (N.ms^{-1})	46.1 ± 21.4	62.7 ± 12.9	94.0 ± 43.4

SD, standard deviation.